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CHARACTERISTICS AND PERFORMANCE OF THE ESTEC LARGE SPACE SIMULATOR CRYOGENIC SYSTEM

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ABSTRACT

With a solar beam of 6 meters, the Large Space Simulator (LSS) at ESTEC, The Netherlands, is one of the world's largest solar simulation facilities (ref. 1).

The design of the LSS cryogenics system, however, provides the facility with the intended flexibility to serve for a variety of thermal test configurations, in addition to solar simulation and mechanical tests. The operational concept of the cryogenics system foresees in automated control of more than 20 modes of operation.

The liquid nitrogen (LN_2) cool-down and circulation circuit as well as the gaseous nitrogen (GN_2) warm-up circuit are completely separated and have individual control of system parameters. Both, the main chamber shroud elements (C1) and the auxiliary chamber (C2) baffle shrouds, can be operated independently or in combination.

Furthermore, it is possible to perform vacuum thermal cycling tests (VTC) by controlling the C1 shroud at temperature levels variable between 100°K and 373°K. The paper presents the final concept and performance characteristics of the LSS cryogenic system.

INTRODUCTION

The performance of the cryogenic system is based on the final acceptance test of the complete LSS facility, performed at ESTEC in April 1986.

The acceptance test involved both solar simulation at the specified 1.8 kW/m^2 radiation level and vacuum temperature cycling during continuous operation of the facility for 400 hours in various configurations. The LSS motion system, which is subject to another procurement contract, will be delivered in 1987 and as a result is not included in the cryogenic test configuration.

TEST ANALYSIS CONCEPT

The standard housekeeping data of the cryogenics system involves a variety of 60 sensors to measure system parameters as flow, level, pressure and temperature. More than 100 dedicated thermo-couples were applied to measure shroud temperatures during the acceptance test.

The data measured by the programmable logic controller (PLC) as well as the PLC status information, was sent to the LSS facility data handling system. The LSS facility data handling provided the following support functions:

- Presentation of data, temperatures, flows, pressure, etc.
- Presentation of system status, valve positions, on/off alarm status, interlocks.
- Presentation of graphs/sensors versus time print-outs, etc.
- Warning and alarm messages.
- Recording of data for problem investigation.
- Recording of data for test reporting.

These features provided high flexibility in adjusting system operations, short fault identification times and analysis of system performance.

Figure 1 shows a typical cool-down and warm-up curve.

THE LIQUID NITROGEN CIRCULATION CONCEPT

For the LN_2 circulation a closed loop pressurised system has been selected, because this concept represents the thermodynamically most suitable system for cooling large shrouds with low operation and investment cost.

In the closed loop pressurised system, the pressure of the liquid nitrogen is increased in the recirculating pump only to the extent needed for overcoming the flow losses in the shroud circuit. The necessary increase in the boiling temperature of the liquid nitrogen in front of the shrouds is achieved by raising the pressure level of the entire circuit so much above normal atmospheric pressure, that liquid nitrogen is available for all operating steps with high heat load.

The liquid nitrogen which is heated up in the shrouds, is cooled again in a heat exchanger and is subsequently immediately pumped back through the shrouds panels by the recirculating pump. The recirculated liquid nitrogen from the shrouds is cooled in the heat exchanger by liquid nitrogen which boils under atmospheric pressure.

In order to build up the necessary positive pressure in the circuit in front of the recirculating pump and for compensating the volume changes resulting from temperature changes, the circuit is connected to a partially nitrogen-filled expansion vessel at the point of lowest pressure in the system.

After the entire system, incl. the shrouds, has been cooled down to the boiling temperature of nitrogen, which occurs at atmospheric pressure, the circuit is raised to the necessary positive pressure by evaporating nitrogen with a reboiler heat exchanger in the expansion vessel. The desired pressure is built up in the expansion vessel by providing a nitrogen gas cushion above the liquid, which is pressure regulated by a closed loop control system.

In the LN_2 circulation mode, after the nitrogen has been cooled and equilibrium has been reached, no evaporation of the recirculated nitrogen occurs in the closed loop system. In contrast to the open pressurised system, the energy for increasing the boiling pressure must be supplied only once when the system is taken into operation.

Since, during this process, the recirculating pump sucks in liquid nitrogen, which is already at a correspondingly high pressure (high NPSH), the risk of cavitation in the recirculating pump, which can occur in the open systems, is eliminated.

The LN_2 inlet temperature of the shrouds is appr. 78°K and the outlet temperature about 83°K. To avoid local boiling of LN_2, the selected system pressure is 8 bar which corresponds with a boiling temperature of 100°K.

The system pressure is controlled by a pressure controller. If deviations from the adjusted setpoint occur, either vaporised N_2 is generated to the expansion vessel or released to the atmosphere if the adjusted pressure is exceeded.

The shrouds in C1 and C2 are subdivided into various circuits (see figure 2); each of them is equipped with flow and temperature measuring control units, installed in the circuit outlet line. By this means, it is possible to adjust individual flow rates, so that an equal temperature difference is provided over each shroud circuit.

The LN_2 nitrogen reboiler has a temperature difference of appr. 5°K between inlet and outlet and is cooled by evaporating LN_2.

THE GASEOUS NITROGEN CIRCULATION CONCEPT

The GN_2 system circulates gaseous nitrogen over the shrouds of the main chamber and auxiliary chamber by means of a rotary piston blower. The suction-side of the blower is protected by a water bath / heat exchanger, which provides either cooling or heating of the incoming gaseous nitrogen to maintain the specified blower temperature limitations.

On the pressure side of the blower, an additional heater is used during the warm-up mode to heat up the shrouds to any temperature level between 273°K and 373°K. A smaller dimension blower / heat exchanger combination is used to maintain the main chamber shrouds at ambient temperature, while the auxiliary chamber shrouds C2 are warmed-up with GN_2.

The GN_2 circuit has alarm and control functions of main system parameters, which are independent of the LN_2 system. Furthermore, each shroud circuit has a separate set of isolation and control valves for LN_2 and GN_2 circulation, so that a wide variety of operational modes is feasible.

VACUUM TEMPERATURE CYCLING MODE

The VTC mode envisages cooling and heating of the main chamber shrouds over a specified temperature range of 173°K to 373°K with a speed of 1°K/min. The VTC mode has been implemented by the addition of a LN_2 injection system into the GN_2 circuit.

A temperature controller works in split range technique and activates either the LN_2 injection valve or the GN_2 heater according to the shroud temperature set-point. A counter flow heat exchanger has been included in the GN_2 circuit to economise the LN_2 consumption.

CRYOGENIC SYSTEM PERFORMANCE

LN_2 COOL-DOWN AND CIRCULATION MODES

Table 1 lists a comparison of the design baseline to the actual system performance, which proves that the requirements have been adequately met. The cool-down / circulation mode is performed and controlled fully automatically by the programmable logic control (PLC).

The maximum temperature increase over the shrouds following switch-on of the sun simulator to the specified 1.8 kW/m^2 solar intensity was measured at 3°K in the 400 hours test configuration. As a result, the LN_2 flow rates through the individual shroud circuits do not have to be modified in dependence of solar intensity levels, providing again a relaxation of pre-test activities.

The flow rate requirements which are shown in table 2 can be met by one LN_2 circulation pump. The second circulation pump is completely redundant and improves significantly the LSS overall reliability. The cryogenic system has been designed and tested for a system pressure of 8 bar, the specified solar intensity level of 1.8 kW/m^2 was, however, accomodated by the shrouds at only 4 bar.

Both, the margin in system pressure and the heat load contingency of 45 kW, will allow thermal and solar simulation tests at higher than specified heat loads and solar intensity levels.

Furthermore, the LN_2 boil-off mode has been implemented. This mode is selected if, due to a malfunction, LN_2 circulation is not feasible. The system is depressurised and the shrouds are operated in a conventional LN_2 boil-off to ambient pressure. LN_2 level in each shroud and refilling is controlled by the PLC automatically. The 400 hours test demonstrated that trouble-shooting of instrumentation and pumps in the circulation system will be feasible without breaking chamber vacuum or draining the shroud circuits by selecting the boil-off mode.

LN_2 DRAINING AND GN_2 WARM-UP MODES

The temperature/time requirements are well within the specification. Typical warm-up times are:

C1/C2 2.5 hours from 100°K to 300°K

C1/C2 6 hours from 100°K to 373°K

These warm-up times are achieved with limited GN_2 inlet temperatures to the shrouds (45°C as compared to an achievable setting of 120°C) and reduced system pressure (4 bar as compared to a design pressure of 6 bar). The contractual requirements are:

- o Warm-up of both C1 and C2 shrouds from 100°K to 373°K within 12 hours.
- o Warm-up of either C1 or C2 shroud from 100°K to 373°K within 8 hours.
- o Temperature stability at 300°K and 373°K shall be ± 10°K.

These specifications have been met with considerable margin to allow the system to be tuned to customer requirements. In fact, any temperature level between 273°K and 373°K can be obtained and controlled during warm-up mode. The warm-up time will now depend on customer allowed temperature gradients over the shrouds, and times as short as 1 hour are feasible.

VTC MODE

Table 3 lists the VTC performance characteristics.

Although the actual performance showed some deviations to the design baseline, the extension of the temperature range down to 105°K is considered a substantial asset in view of the tendency of present customer requirements towards lower temperature limits. The installation of the counterflow heat exchanger introduces a significant reduction in LN_2 consumption; some examples are shown in table 4.

Finally, the VTC mode has many control parameters which require additional tuning. Continued testing during 1986 will provide an optimum VTC performance, which has again the potential to be adapted to customer requirements.

SHROUD PERFORMANCE

In the past, most of the space simulators have been equipped with Al-shrouds due to their good thermal conductivity, low weight and lower cost. Recently, Al-shrouds in service have experienced thermal vacuum cracks and new cracks have appeared during each thermal vacuum test.

The stainless steel shrouds incorporated in the LSS cryogenics system demonstrated excellent performance during various warm-up and LN_2 cool-down / circulation phases. The specified leak tightness, being:

- Individual leak rate $<10^{-4}$ mbar l/s.
- Integral leak rate $<10^{-3}$ mbar l/s.

Typical leak rates were better than 10^{-6} mbar l/s. The shroud design in the main chamber is self supporting, avoiding mechanical stress due to temperature gradients between shroud and chamber. The number of dismountable couplings is restricted to a minimum. Both factors increase shroud leak integrity and reliability.

The installation of the majority of internal pipes and headers on the shroud inner chamber side, as well as the baffle principle in the auxiliary chamber, allow easy maintenance and repair. The disadvantage of the moderate thermal conductivity and the higher weight of the stainless steel shrouds is compensated by the improved reliability and maintainability in particular with respect to leak tightness.

Also the baffle principle has demonstrated the advantages of free access to chamber walls to build-up platforms for facility maintenance and cleaning.

CONCLUSIONS

The LSS cryogenics system has proven its operational capabilities under simulated heat load conditions and provides sufficient margin for future elevated requirements.

The high level of instrumentation and operational sophistication allows facility operations with minimum staff. The acceptance test proved that nominal operating pressures can be lower than the design parameters, providing increased system safety and reliability. The ease of access for repair and the incorporated reduncancy will limit system down-time. Finally, the system design resulted in a low consumption of LN_2, which is an important factor in keeping the operational costs at a low level.

REFERENCES

1. Brinkmann, P.W., October 1985, Main Characteristics of the Large Space Simulator (LSS) at ESA/ESTEC, NASA CP 2340, proceeding of the 13th Space Simulation Conference, Orlando, Florida.

TABLE 1: LN_2 COOL-DOWN AND CIRCULATION MODE PERFORMANCE

PARAMETER	DESIGN	ACTUAL
Total heat load at 1.8 kW/m^2 solar power	135 kW	125 kW
System contingency	35 kW	45 kW
LN_2 consumption		
Cool-down	20 m^3	17 m^3
LN_2 circulation with 1.8 kW/m^2	4.5 m^3/h	2.7 m^3/h
LN_2 circulation without sun	2.8 m^3/h	1.8 m^3/h
System pressure to avoid LN_2 vaporisation	8 bar	down to 2 bar
Temperature increase over LN_2 circuit	5°K	3°K
LN_2 flow	72 m^3/h	82 m^3/h
Shroud temperature	100°K	100°K
Cool-down time	within 2 hours	within 2 hours

TABLE 2: SHROUD LN_2 FLOW RATE REQUIREMENTS

SHROUD CIRCUIT		SHROUD SURFACE (M^2)	FLOW RATE (M^3/H)	
			DESIGN *	ACTUAL
Top shroud	C1-1	71	4	8
Bottom shroud	C1-2	67	4	7
Lower cylinder	C1-3	90	18	19
Upper cylinder	C1-4	110	18	21
5 meter door	C1-5	31	8	9
8 meter nozzle and spout	C2-1	84	10	8
Baffle shrouds	C2-2	103	10	11
TOTAL	C1/C2	594	72	78 **

* Based on thermodynamic analysis of shroud circuits at 1.8 kW/m^3 solar intensity level.

** The difference between the sum of individual flow rates and the LN_2 pump capacity is due to a LN_2 by-pass line.

TABLE 3: VTC MODE PERFORMANCE

PARAMETER	DESIGN	ACTUAL
Cl temperature levels variable between	173°K - 373°K	105°K - 373°K
Rate of change of shroud temperatures	1°K/min. 173°K - 373°K	1°K/min. 105°K - 353°K 5°K/min. 353°K - 373°K
Temperature distribution at stabilised temperature	± 5°K	± 10°K

TABLE 4: VTC HEAT EXCHANGER ECONOMY

CASE	LIQUID NITROGEN CONSUMPTION (KG/H)	
	WITHOUT HEAT EXCHANGER	WITH HEAT EXCHANGER
173°K constant	2165	450
173°K cooling, 1°K/min.	3753	1858
273°K constant	572	245
273°K cooling, 1°K/min.	1629	1294

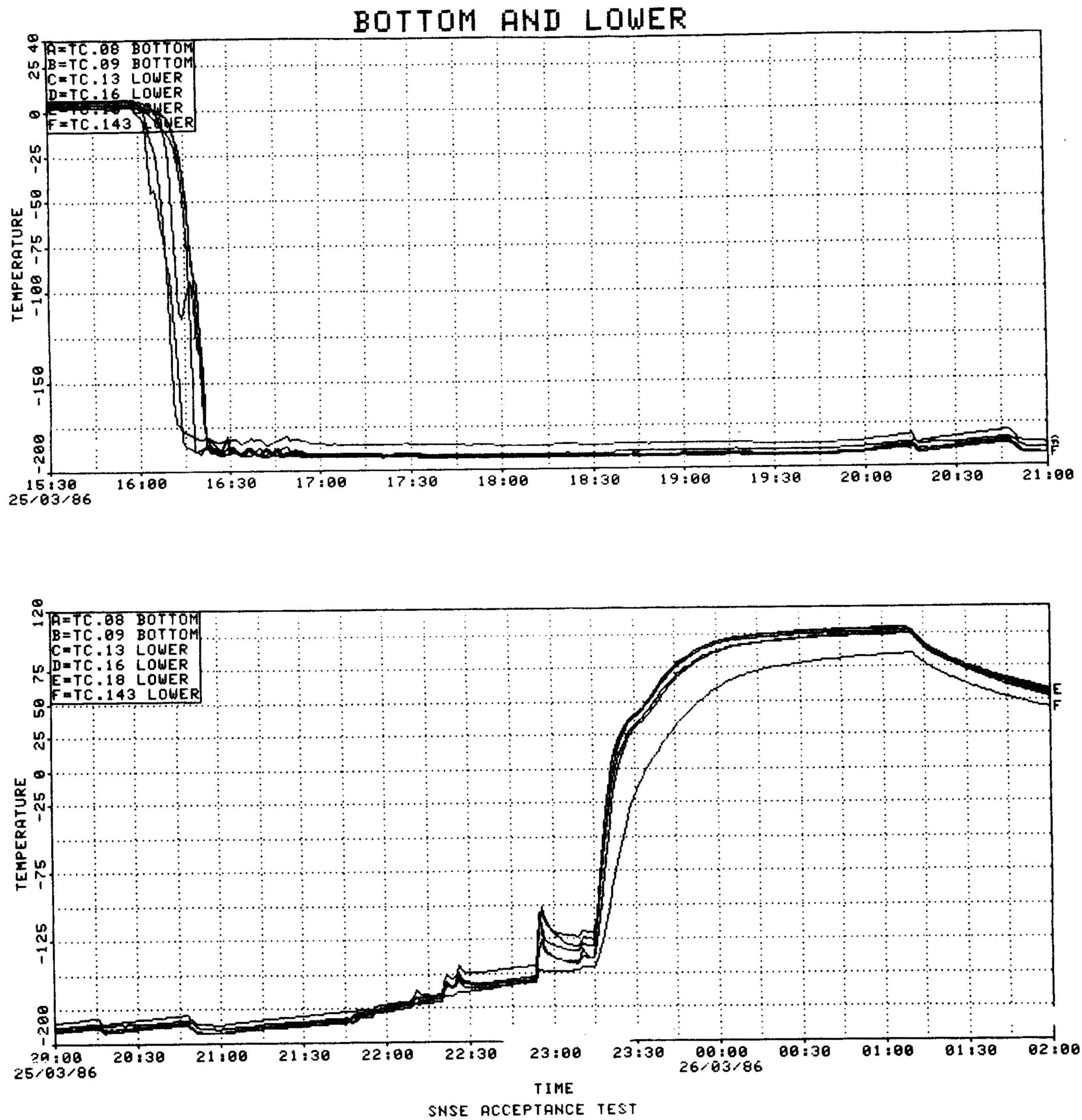

Figure 1. Typical cool-down and warm-up curve of a shroud

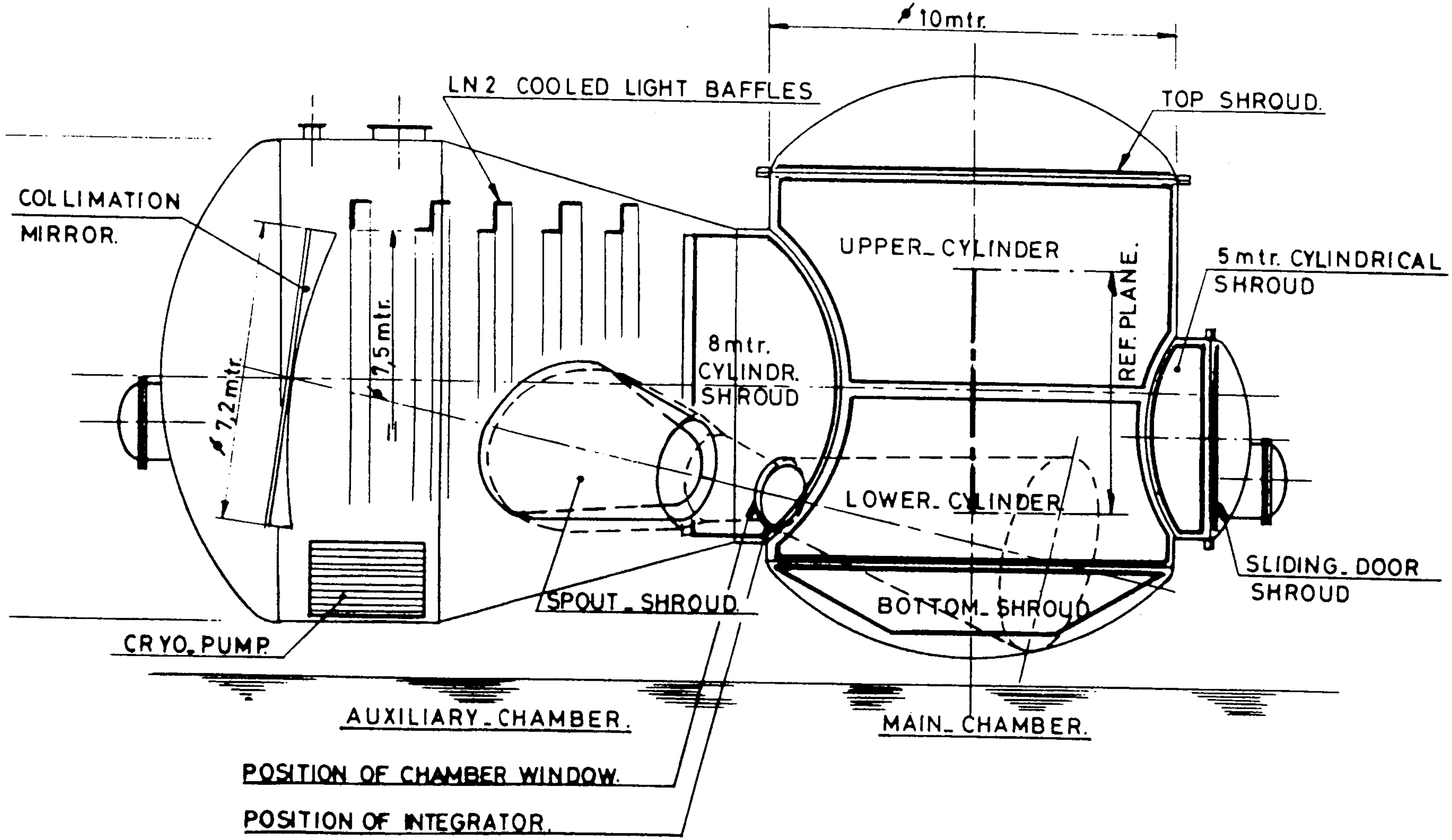

Figure 2. Layout of shroud elements